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Dual-band frequency reconfigurable 5G microstrip antenna

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Abstract
Microstrip Antenna is widely developed and used in modern telecommunications equipment because of its advantages. Microstrip antenna is also used in 5G development which is expected to increase communication capacity and also be able to provide very large data rates. The frequency used in 5G is 28, 38, and 78 GHz. However, the 5G network with high frequency has a weakness: transmitted waves are vulnerable to weather because of their dense waveform. Therefore, the multiband is used to support different frequencies in one antenna. Furthermore, antenna reconfiguration is used to set the antenna to work on a different frequency and adjust different radiation patterns depending on the needs without changing the form of the antenna. This paper proposes the dual-band frequency reconfigurable antenna with RT Duroid 5880 as its substrate using PIN diodes placed between the main patch and secondary patch element and simulated on CST software for 28 GHz and 38 GHz with two conditions, ON and OFF. Both simulated and measured results show that the antenna can work well as intended. During the OFF condition, the antenna only works at 38 GHz, while in the ON condition, the antenna works at 28 GHz and 38 GHz, respectively.

Keywords:
5G;
Diode;
Microstrip Antenna;
Reconfigurable;

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INTRODUCTION

The industrial transformation that is happening globally has led to many improvements in people's daily life, including communication technology. The 5G is the next-generation mobile communication technology that improved Long Term Evolution (LTE) technology. 5G is expected to provide the user with improved services at ultra-high-speed data rates at low latency, support higher connectivity, and improve the bandwidth capacity [1]. Some tools are also used in 5G technologies, such as an antenna.

Microstrip antenna is widely developed and used in modern telecommunications equipment. It is because of many methods and techniques in the antenna design and applications [2], and the antenna keeps shrinking in size [3], simple shape, lightweight, easy to fabricate, easy to integrate, and cheap [4]. Microstrip antenna consists of a substrate and thin metallic acting as patch radiating element and the ground placed on the substrate surface. Microstrip patch antenna can be designed in many shapes like circular, rectangular, and triangle [5].

There are many applications of the microstrip antenna. One of them is the 5G antenna which is still intensively developed. The frequency in the mm-wave range that is approved by WRC-15 is 24.25 – 27.5 GHz, 31.8 – 43.5 GHz, 45.5 – 50.2 GHz, 50.4 – 52.6 GHz, 66 – 76 GHz, and 81 – 86 GHz. These bands are usually used for local and personal communication [6].

The 5G network that uses high frequency has an emitting waveform that is sufficiently dense so that the transmitted wave is very vulnerable to weather [7]. Multiband supports using different frequencies to produce a good gain and radiation pattern. This multiband antenna can synchronize electromagnetic signals at all frequencies, supported primarily at the desired frequency [8]. Multiband antennas are also used because they can replace two or more antennas that are separated into one antenna only, reducing the complexity of the antenna [9].

A single antenna can be reconfigured for multiple parameters [10]. Antenna reconfiguration sets the antenna to work at a particular frequency depending on needs. This multiband antenna can be configured by adding a switch to the antenna's patch element to determine the antenna's working frequency [11]. A reconfigurable frequency antenna can avoid interruption from different unused frequency bands, thus reducing the demand for filters and simplifying the antenna's shape [12].

This reconfigurable antenna is the best candidate for a software-defined radio, which can quickly adapt to the surrounding environment and change its function as intended [13]. Reconfiguration antenna can be done using several components, including RF PIN diodes, varactor diodes, and Radio Frequency Micro Electromechanical System (RF MEMS) switches [14]. The PIN diodes have the advantages of a low loss rate and low cost and are often implemented as a reconfigurable antenna. RF-MEMS are more used when power consumption is low and has wide impedance bandwidth, and a varactor diode adjusts the tuning frequency faster [15], [16].

There has been much research on the design of reconfigurable antennas. For example, research [17] studied frequency reconfigurable microstrip antenna achieved by changing the state from the RF switch and using five PIN diodes placed on the patch antenna surface and then connected to the PIC microcontroller. This research gives some conditions, with the results obtained vary depending on the conditions determined earlier. The results work in the frequency range of 850 MHz to 3.3 GHz.

Another research [18] designed an antenna as a mobile PCB with eight slots shaped like the letter T on the top of the PCB. A pair of PIN diodes are placed in the T slot for the antenna to work as a reconfigurable antenna that can change the frequency from 38 GHz to 28 GHz. This research designs an antenna that works on a particular frequency according to the state of the diode.

The paper [19] proposed two antenna designs working on two modes, single-band and dual-band. The antenna is shaped like the number 9 (nine) and epsilon. The frequency in dual-band mode is 2.45 and 5.20 GHz, while in single-band mode is 3.50 GHz.

Several studies proposed reconfigurable antenna design using a PIN diode connected to the antenna to act as a switch with biasing line and Arduino as the reconfiguration setting. In the paper [20], the frequency works at 2.47 GHz, 3.8 GHz, and 5.36 GHz. The paper [21] proposes a MIMO design with the frequency working at 2.4 GHz and 2.6 GHz given different conditions. And paper [22] proposes an antenna with an L slot using two pin diodes placed on the slot to change the working frequency from 4.75 GHz to 5.18 GHz based on the given condition.

The paper [23] presents an N-shaped frequency reconfigurable antenna. Two PIN diodes are used as an auto-switching unit with the help of an Arduino UNO microcontroller. The auto-switching unit is given different conditions to change every 5s delay. The result obtained varies from 1.2 GHz to 6.8 GHz.

This research mainly focused on reconfiguring the frequency of the microstrip antenna applied with a PIN diode acting as the switch between the two patch elements to enable different configurations. This reconfigurable frequency antenna works on 5G frequencies, 28 GHz, and 38 GHz. It will be given two conditions: ON and OFF. This paper is organized as follows: the antenna design with its parameter will be discussed in the antenna design section. Then the simulation and measurement results will be described in the results and discussions section. Finally, this concludes all the results and analyses obtained.

METHOD

Antenna Design

The antenna design will use two rectangular-shaped patches as the radiating element. The proposed frequency reconfigurable 5G antenna is depicted in Figure 1.

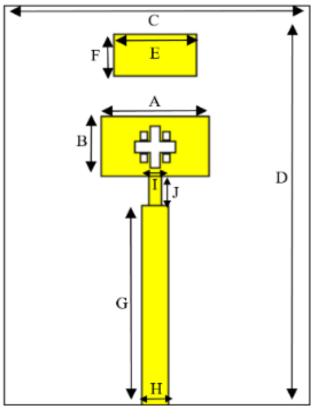


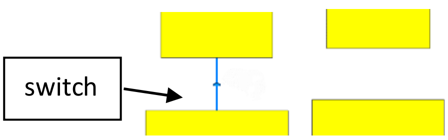
Figure 1. Geometry dual-band frequency reconfigurable 5G antenna

RT Duroid 5880 is the substrate with a dielectric constant (ε_r) 2.2. Substrate height (h) 0.254 mm, loss tangents (tan δ), and copper thickness = 0.035. Because of its dielectric constant, RT Duroid is suitable for high-band applications [24]. Plus (+) slot with four small square-shaped slots in each corner is placed on the main patch element to give a better result. The MA4AGBL912 PIN diode is used because it is suitable for high frequencies up to 40 GHz. The antenna parameters are listed in Table 1.

Simulation is done with two conditions which are ON and OFF. First, the lumped element is placed between the radiation patches and acts as a diode switch to determine the ON condition. In the OFF condition, the lumped element that has been placed between the radiation patches is removed, as shown in Figure 2.

Table 1. Parameter of the frequency reconfigurable antenna

Dimension	Value (mm)
A	5.2
B	2.9
C	15
D	20
E	4
F	2
G	10
H	1.25
I	0.625
J	1.4



(a) (b)

Figure 2. (a) ON condition (b) OFF condition

The antenna design specification in this research is presented in Table 2. The characterization of the antenna is done by adding a plus (+) shaped slot in the main radiation element. The slot parameters are shown in Table 3.

The purpose of the slot is to shift the working frequency to obtain the desired frequency at 38 GHz in the main element without changing the shape and size to increase the antenna efficiency as well for novelty [25].

RESULTS AND DISCUSSION

The simulated result of the S parameter antenna resulted from the antenna on both condition configurations is shown in Figure 3. Figure 3 shows the S11 results in 28 GHz only work at ON condition with an S11 value of -10.805 dB that already satisfies the minimum S11 value. The frequency cannot work properly in the OFF condition at 28 GHz because the S11 value is only at -5.3 dB. For 38 GHz, both ON and OFF conditions can work properly, given that the S11 value is -10.041 dB and -31.215 dB, which already meet the minimum requirement of -10 dB.

Table 2. Design specification of the antenna

Parameter	Specification
Frequency (GHz)	28 & 38 /38
S11 (dB)	≤ -10
Gain (dBi)	≥ 8
Bandwidth (MHz)	≥ 350

Table 3. Slot Parameters

Parameters	Value (mm)
Length of the main (+) slot	2
Width of the main (+) slot	0.5
Length of the additional square slot	0.36
Width of the additional square slot	0.4

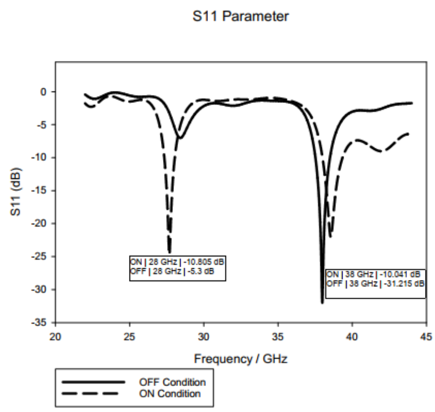


Figure 3. S11 parameter of the dual-band frequency reconfigurable antenna ON and OFF condition

Figure 4 and Figure 5 show the directivity gained from the simulation in each condition. In Figure 5, the obtained gain for 38 GHz at OFF condition is 8.36 dBi. The gain in ON condition shown in Figure 9 for the frequency 28 GHz and 38 GHz is 8.5 dBi and 8.51 dBi, respectively. This shows that both conditions have high antenna gain for each working frequency.

Figure 6 shows the 2D radiation pattern for a realized gain of 38 GHz in OFF condition. The E-Plane is obtained while Phi=0, and H-Plane is obtained when the Phi=90. The realized gain obtained in E-Plane and H-Plane is relatively high for 7.55 dBi and -5.45 dBi, respectively.

Figure 7 is the 2D graphics of the co-polarization and the cross-polarization of the antenna, where Figure 7(a) shows the co-polarization and cross-polarization of theta and Figure 7(b) shows the co-polarization and cross-polarization of phi. The co-polarization of theta is obtained when the phi=90, while the cross-polarization of theta is obtained when phi=0. Meanwhile, phi co-polarization is obtained when phi=0, and cross-polarization of phi is obtained when phi=90.

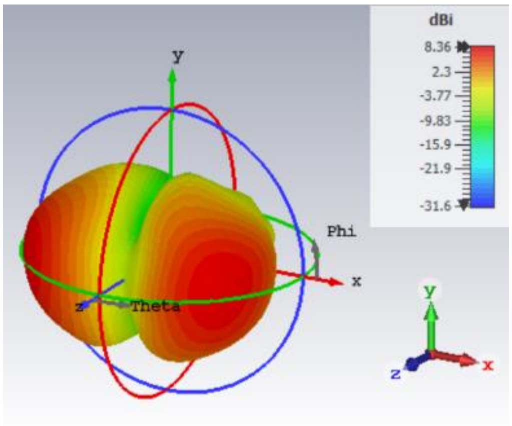
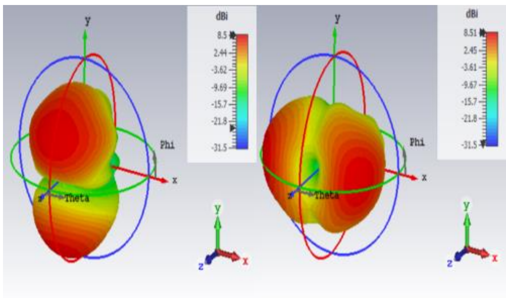
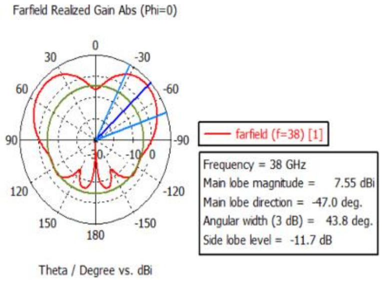


Figure 4. Simulated directivity frequency reconfigurable antenna OFF condition at 38 GHz

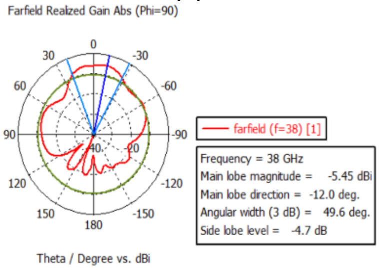


(a) (b)

Figure 5. Simulated directivity frequency reconfigurable antenna ON condition (a) 28 GHz (b) 38 GHz

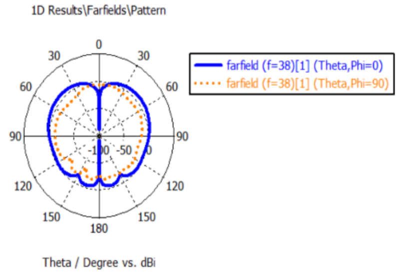


(a)

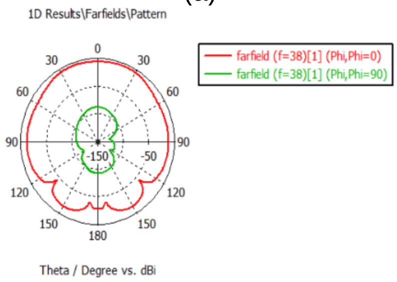


(b)

Figure 6. 2D radiation pattern of the 38 GHz in the OFF condition (a) E-Plane (Phi=0) (b) H-Plane (Phi=90)



(a)



(b)

Figure 7. Co-polarization and cross-polarization of the (a) Theta and (b) Phi of the 38 GHz in OFF condition

Figure 8 shows the realized gain 2D radiation pattern for 28 GHz in ON condition for E-Plane, -7.11 dBi and H-Plane 4.14 dBi. Figure 9 shows the realized gain 2D radiation pattern for 38 GHz in ON condition for E-Plane, 6.98 dBi and the realized gain in the H-Plane is small for only -2.52 dBi.

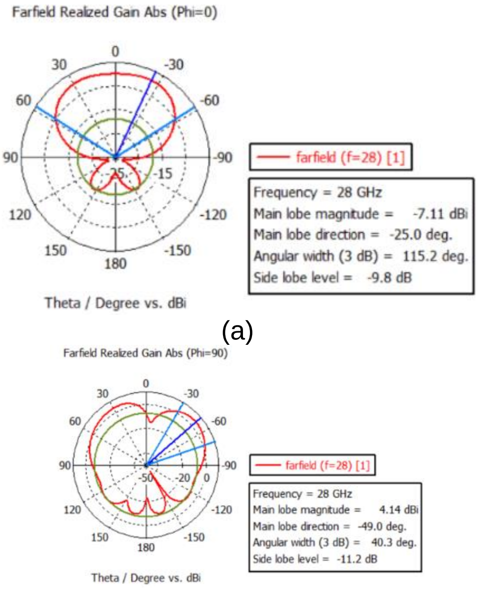


Figure 8. 2D radiation pattern of the 28 GHz in the ON condition (a) E-Plane (Phi=0) (b) H-Plane (Phi=90)

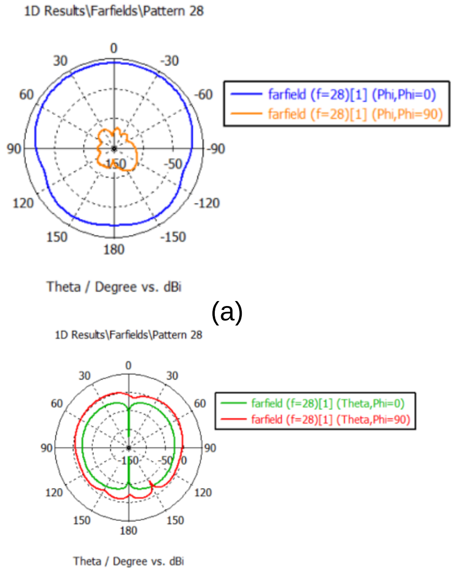


Figure 10. Co-polarization and-cross polarization of the (a) Phi and (b) Theta of the 28 GHz in ON condition

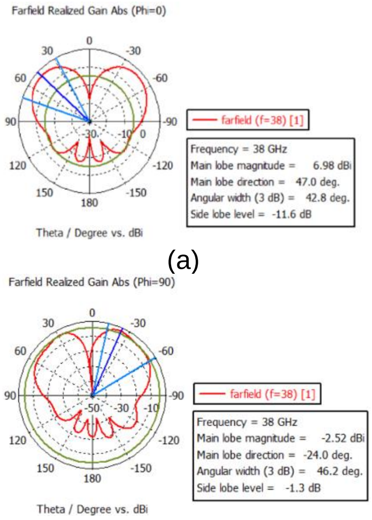


Figure 9. 2D radiation pattern of the 38 GHz in the ON condition (a) E-Plane (Phi=0) (b) H-Plane (Phi=90)

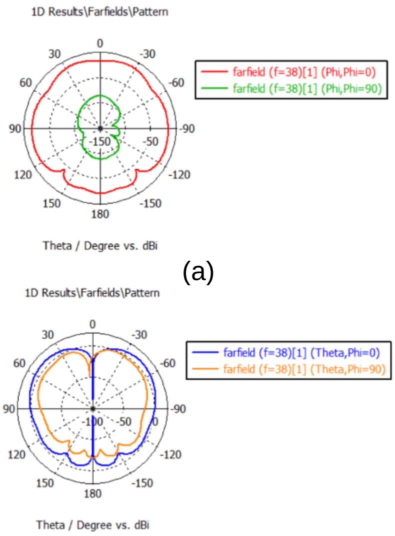
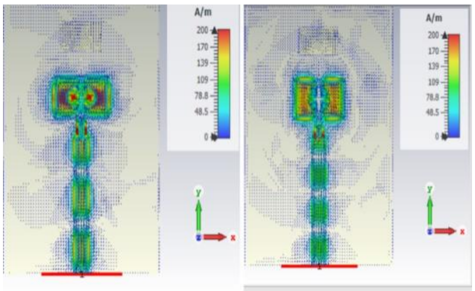


Figure 11. Co-polarization and cross-polarization of the (a) Phi and (b) Theta of the 38 GHz in ON condition

Figure 10 and Figure 11 show the graphics of the co-polarization and cross-polarization of the antenna in 28 GHz and 38 GHz in the ON condition. Figure 10(a) and Figure 11(a) show the co-polarization and cross-polarization of Phi, and Figure 10(b) and Figure 11(b) show Theta's co-polarization and cross-polarization.

Figure 12 shows the simulated current flow on the reconfigurable antenna in the condition of the diode OFF, which only works at a frequency of 38 GHz. It shows that the current flow only enters the main radiating element with a current value of the maximum set in the measurement is 200 A/m. The average value of the incoming current is around 109 to 170 A/m, which implies that the surface current flows in this antenna quite well. While in the second radiating element, there is no incoming current, so at a frequency of 28 GHz cannot operate in the OFF condition.



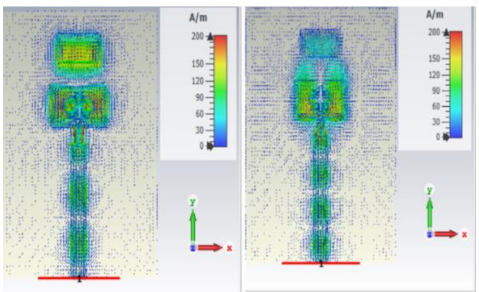
(a) (b)

Figure 12. Simulated current flow on reconfigurable antenna OFF condition (a) 28 GHz (b) 38 GHz

Figure 13 shows the antenna current flow in the ON condition. At 28 GHz, the current flows into both radiating elements; thus, it can work well with the maximum value of 200 A/m. The value of the average current flowing on the surface of this antenna is around 90 to 150 A/m, which shows that the current can flow on the surface quite well. At 38 GHz, the current flow is entirely focused on the main radiating element, while the second radiating element has a relatively low current flow. This shows that in the ON condition, the antenna can work well to transmit the frequencies of 28 GHz and 38 GHz simultaneously.

The simulated results from the frequency reconfigurable antenna have shown that the proposed antenna design works appropriately with the different given condition, which is ON and OFF. Furthermore, applying the diode between the two patch elements results in different working frequencies.

The result comparison of the simulated frequency reconfigurable antenna can be shown in Table 4. Table 4 shows the comparison results for each condition which implies that the antenna is working correctly with the diode to act as a switch controlling the ON and OFF condition.



(a) (b)

Figure 13. Simulated current flow on reconfigurable antenna ON condition (a) 28 GHz (b) 38 GHz

Table 4. The result comparison of OFF and ON conditions of the simulated antenna

Parameter	OFF 28 GHz	OFF 38 GHz	ON 28 GHz	ON 38 GHz
S11(dB)	-5.3	-31.215	-10.805	-10.041
Gain (dBi)		8.36	8.5	8.51
Bandwidth (MHz)	0	36	228	198

The simulation result between the ON and OFF conditions already satisfies the design specification for S11 and gain. However, the bandwidth does not satisfy the requirement for 5G.

The fabricated antenna is shown in Figure 14. The size of the antenna is tiny because of its high frequency. Therefore, the fabricated antenna is measured manually to observe the antenna's performance before being integrated with the switch and microcontroller. The copper tape connects the first and second patches during ON conditions.

The measured S11 of the fabricated antenna is shown in Figure 15. It shows that the antenna can function as intended in both ON and OFF conditions. The working frequency in the ON condition is 28.18 GHz and 35.68 GHz, with an S11 of -24.25 dB and -29.4 dB, respectively.

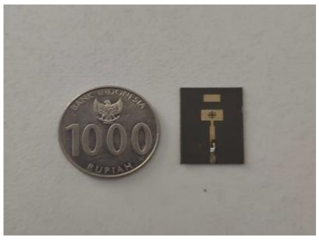


Figure 14. The fabricated frequency reconfigurable antenna

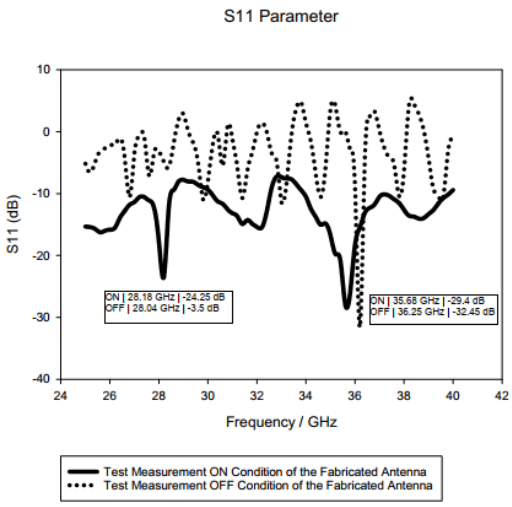


Figure 15. Measured S11 parameter of the fabricated antenna in ON and OFF condition

While in the OFF condition, the frequency 28 GHz only has an S11 value of -3.5 dB and the lowest S11 value at -32.45 dB on 36.25 GHz. The comparison of the simulated and measured results is shown in Table 5.

As shown in Table 5, the reconfigurable antenna can work adequately given the different conditions. In the ON condition, the working frequency is 28 and 38 GHz, while in the OFF condition, the working frequency is only 38 GHz. However, some measured frequencies are shifted due to many factors, such as fabrication, antenna soldering, and port feeding. The measurement process can also affect the antenna result.

The comparison of this research and existing research is presented in Table 6. The comparison is based on the simulation result. The frequency used varies from 850 MHz to 38 GHz. The research [13] focused on changing frequency through various simulations resulting in frequencies ranging from 850 MHz to 3.3 GHz. These authors also focused on radiation patterns; thus, the S11 and gain are not presented. The research [14] has a similar working frequency to our paper; however, the working frequency is only at a single band; given the diode condition, the frequency works only at 28 GHz or 38 GHz.

This paper also focused on beam steering resulting in S11 and gain being absent. Research [15] runs many simulations in different conditions resulting in the working frequency is ranged from 1.2 GHz to 6.8 GHz. The S11 Parameter is also not presented in this research. However, this research comparing gains obtained from its different states ranged from 2.7 to 3.4 dBi.

Table 5. Comparison of the simulated and measured parameters

	Simulated ON	Fabricated ON	Simulated OFF	Fabricated OFF
Frequency (GHz)	28/38	28.18/35.68	28/38	28.04/36.25
S11 (dB)	-10.805/ -10.041	-24.25/ -29.4	-5.3/ -31.215	-3.5/-32.45
Bandwidth (MHz)	228/198	1339/3409	0/35	0/316

Table 6. Comparison with existing research

Research	Frequency (GHz)	S11(dB)	Gain (dBi)
This Research	28 & 38/38	-10.805 & -10.041/ -31.215	8.36 – 8.51
[13]	0.85 – 3.3	-	-
[14]	28 / 38	-	-
[15]	1.2 – 6.8	-	2.7 – 3.4

CONCLUSION

The frequency-reconfigurable antenna with two radiating patch elements connected by a diode acting as a switch to control the given condition can affect the working frequency. In the ON condition, the current will flow into the second patch element, thus will activate both operating frequencies to make the antenna work as a dual-band in the 28 GHz and 38 GHz. In contrast, in the OFF condition, the current cannot flow into the second patch element resulting in only one working frequency from the main patch element at 38 GHz.

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REFERENCES

[1] A. Dogra, R. K. Jha, and S. Jain, “A Survey on Beyond 5G Network with the Advent of 6G: Architecture and Emerging Technologies,” *IEEE Access*, vol. 9, pp. 67512–67547, 2021, doi: 10.1109/ ACCESS.2020.3031234.

[2] O. Darboe, D. B. O. Konditi, and F. Manene, “A 28 GHz rectangular microstrip patch antenna for 5G applications,” *International Journal of Engineering Research and Technology*, vol. 12, no. 6, pp. 854–857, 2019.

[3] R. Mishra, R. G. Mishra, R. K. Chaurasia, and A. K. Shrivastava, “Design and analysis of microstrip patch antenna for wireless communication,” *International Journal of Innovative Technology and Exploring Engineering*, vol. 8, no. 7, pp. 663–666, 2019.

[4] M. S. F. Reyhan, Y. Rahayu, and F. Muhammadsyah, “The Design of Broadband 8x2 Phased Array 5G Antenna MIMO 28 GHz for Base Station,” *International Journal of Electronics and Communication Engineering*, vol. 12, no. 11, pp. 825–828, 2018.

[5] D. Rusdiyanto, C. Apriono, D. W. Astuti, and M. Muslim, “Bandwidth and gain enhancement of microstrip antenna using defected ground structure and horizontal patch gap,” *SINERGI*, vol. 25, no. 2, pp. 153–158, 2021, doi: 10.22441/sinergi.2021. 2.006

[6] M. Shafi *et al.*, “5G: A tutorial overview of standards, trials, challenges, deployment, and practice,” *IEEE journal on selected areas in communications*, vol. 35, no. 6, pp. 1201–1221, 2017, doi: 10.1109/JSAC.2017.2692307.

[7] F. Qamar *et al.*, “Investigation of future 5G-IoT millimeter-wave network performance at 38 GHz for urban microcell outdoor environment,” *Electronics (Basel)*, vol. 8, no. 5, p. 495, 2019.

[8] M. U. Hassan, F. Arshad, S. I. Naqvi, Y. Amin, and H. Tenhunen, “A Compact Flexible and Frequency Reconfigurable Antenna for Quintuple Applications.,” *Radio engineering*, vol. 26, no. 3, 2017.

[9] A. Khidre, F. Yang, and A. Z. Elsherbeni, “A patch antenna with a varactor-loaded slot for reconfigurable dual-band operation,” *IEEE Trans Antennas Propag*, vol. 63, no. 2, pp. 755–760, 2014, doi:

[10] S. Dubal and A. Chaudhari, “Mechanisms of reconfigurable antenna: A review,” in *2020 10th International Conference on Cloud Computing, Data Science & Engineering (Confluence)*, 2020, pp. 576–580.

[11] S. A. A. Shah, M. F. Khan, S. Ullah, A. Basir, U. Ali, and U. Naeem, “Design and measurement of planar monopole antennas for multiband wireless applications,” *IETE J Res*, vol. 63, no. 2, pp. 194–204, 2017.

[12] T. Li, H. Zhai, X. Wang, L. Li, and C. Liang, “Frequency-reconfigurable bow-tie antenna for Bluetooth, WiMAX, and WLAN applications,” *IEEE Antennas Wirel Propag Lett*, vol. 14, pp. 171–174, 2014.

[13] H. C. Mohanta, A. Kouzani, and S. K. Mandal, “Reconfigurable antennas and their applications,” *Universal Journal of Electrical and Electronic Engineering,* vol. 6, no. 4, pp. 239-258, 2019.

[14] V. Arun, “A Compact Frequency Tunable Microstrip Patch Antenna using Switching Mechanism for Wireless Applications,” *International Journal of Applied Engineering Research*, vol. 10, no. 19, p. 2015, 2015.

[15] A. P. Deo, A. Sonker, and R. Kumar, “Design of reconfigurable slot antenna using varactor diode,” in *2017 International Conference on Computer, Communications and Electronics (Comptelix)*, 2017, pp. 511–515.

[16] N. Ojaroudi Parchin, H. Jahanbakhsh Basherlou, Y. I. A. Al-Yasir, A. M. Abdulkhaleq, and R. A. Abd-Alhameed, “Reconfigurable antennas: Switching techniques—A survey,” *Electronics (Basel)*, vol. 9, no. 2, p. 336, 2020.

[17] S. Genovesi, A. Monorchio, M. B. Borgese, S. Pisu, and F. M. Valeri, “Frequency-reconfigurable microstrip antenna with biasing network driven by a PIC microcontroller,” *IEEE Antennas Wirel Propag Lett*, vol. 11, pp. 156–159, 2012.

[18] N. Ojaroudi Parchin *et al.*, “Frequency reconfigurable antenna array for mm-Wave 5G mobile handsets,” in *International conference on broadband communications, networks and systems*, 2018, pp. 438–445.

[19] S. Ullah, S. Hayat, A. Umar, U. Ali, F. A. Tahir, and J. A. Flint, “Design, fabrication and measurement of triple band frequency reconfigurable antennas for portable wireless communications,” *AEU-International Journal of Electronics and Communications*, vol. 81, pp. 236–242, 2017.

[20] A. A. Palsokar and S. L. Lahudkar, “Frequency and pattern reconfigurable rectangular patch antenna using single PIN diode,” *AEU-International Journal of Electronics and Communications*, vol. 125, p. 153370, 2020.

[21] E. A. Kadir, H. Irie, S. K. A. Rahim, Y. Arta, and S. L. Rosa, “Reconfigurable mimo antenna for wireless communication based on arduino microcontroller,” in *2018 IEEE International RF and Microwave Conference (RFM),* pp. 119-122.

[22] B. Saikia, P. Dutta, and K. Borah, “A compact dual asymmetric L-slot frequency reconfigurable microstrip patch antenna,” *Progress in Electromagnetics Research C*, vol. 113, pp. 59–68, 2021.

[23] V. Arun, L. R. KarlMarx, J. K. J. Kumar, and C. C. Vimlitha, “N-shaped frequency reconfigurable antenna with auto switching unit,” *The Applied Computational Electromagnetics Society Journal (ACES)*, pp. 710–713, 2018.

[24] A. S. A. Nisha, R. Narmadha, and T. Bernatin, “Comparative Analysis of Different Dielectric Materials with Diverse Thicknesses,” *International Conference on Recent Trends in Computing, Communication and Networking Technologies*, 2019.

[25] N. Gupta, “Effects of slots on microstrip patch antenna,” *International Research Journal of Engineering and Technology (IRJET)*, vol. 4, no. 2, pp. 1132–1135, 2017.